Michael Nentwich

CYBERSCIENCE: MODELLING ICT-INDUCED CHANGES OF THE SCHOLARLY COMMUNICATION SYSTEM

The use of information and communication technologies (ICT) is changing science and research. This paper focuses on the complex process of change of the scholarly communication system and how on we may explain the differences of ICT use among research fields. The author submits a heuristic model of change that sets ICT initially as an independent variable and systematizes a series of intervening variables. He distinguishes between institutional, functional/technical and actor-related factors that contribute to our overall understanding of the path of academe towards 'cyberscience'. It turns out that the ICT-induced development and hence the differences between research specialities cannot be explained by a small, parsimonious set of factors. The resulting picture is one of multiple causation with a strong emphasis on cultural aspects.

Keywords Information and communication technologies; academe; science and research; scholarly communication system; Internet; cyberscience

Introduction

Since the early 1980s, the scholarly community has used more and more information and communication technologies (ICT). The networked PC, email, online databases, the World Wide Web, E-journals, discussion lists, E-conferences and digital libraries are but a few of the trends that increasingly influence the daily work of the scientific community. 'Papers' such as this, for instance, are written on a PC, using many online resources, sent to the journal via email, published both in print and online, accessible in online databases. As opposed to 'traditional' science and research, which has done without networked computers, the notion of 'cyberscience' refers to the use of these

Information, Communication & Society Vol. 8, No. 4, December 2005, pp. 542–560
Routledge Taylor & Francis Group
ISSN 1369-118X print/ISSN 1468-4462 online
http://www.tandf.co.uk/journals DOI: 10.1080/13691180500418451

ICT-based applications and services in academe (including the humanities and social sciences). Cyberscience encompasses all scholarly and scientific research activities in the virtual space generated by the networked computers and by advanced ICT (Nentwich 1999; see also Wouters 1996; Walsh & Roselle 1999, p. 50).

Cyberscience is affecting practically every aspect of how research is done. The obvious question to ask is how exactly ICT[1] use affects academe. Putting this general question, we have in mind the possible consequences of the use of the new media for the structures of academe, the production of content or communication styles. While the larger study on which this paper is based includes an encompassing analysis of all kinds of impacts of ICT on academe as a whole (Nentwich 2003, pp. 183–462), this paper will focus on the *immediate changes of the scholarly communication system (SCS)*.

Among the various types of scholarly activities, scholarly communication holds a central place and is linked with production and distribution of knowledge. Scholarly discourse and cooperation would be unthinkable without communication. Publications are the products of scholarly communication. However, even knowledge production involves a good deal of communication, namely with the object of research (Gibbons *et al*. 1994, pp. 36ff.). Furthermore, the distribution of knowledge is inherently a communicative endeavour, as are project acquisition and certain aspects of the organization of science and research (academe as a network of communicating people with different specializations). To a very large degree, science and research is communication.

In this paper, I shall focus on *how we may explain the differences between the academic fields*.The answer to this question is by no means trivial. First, because cyberscience is a moving target, as the technology and the applications are constantly evolving. Second, the evolution of science and research is not only triggered by technology alone. Rather, a number of additional factors, such as the general science policy environment, play a role here as well. Third, there are many differences between the various disciplines and fields. Hence, it is understandable that, so far, there have been only rather narrow studies focusing on particular aspects or fields, but never conceptualizing the development as a whole.

With a view to coping with this complexity, this paper puts forward a flexible heuristic model that generates and evaluates a broad array of factors influencing the evolution of the science system towards cyberscience. In a second step, the paper reports key empirical findings by putting the hypotheses generated to an empirical test. Our test bed is the status quo of ICT use in 13 academic disciplines. The data stem from 50 expert interviews,[2] the STS literature and an extensive Internet inquiry (Nentwich 2003, pp. 11ff.).

The change model

The SCS is changing from the 'traditional', pre-ICT situation towards a state in which ICT play a significant although not necessarily all-encompassing role. I chose to label this future state 'cyberscience'. In between, that is today, academe is in a transitory status quo. Obviously, the diffusion of these new media technologies and numerous value-added services is well under way. This is by no means a linear process and it differs from field to field. Although the elements of the academic Internet may be considered to be a technology cluster (Rogers 1995, p. 15), as its elements are closely interrelated and often come as a package, the adoption rates of these elements is not the same for all. For instance, email and access to the World Wide Web are already practically universal, while groupware and video-conferencing are only at the beginning of their potential S-shaped diffusion curves of adoption. I call 'cyberness' the level of ICT use of an academic field, speciality or discipline, in other words the relative position on a (hypothetical) combined diffusion curve of the various forms of ICT use.

The intermingled diffusion processes do not take place in a vacuum. While, at the end of the day, it is the individual actor, the scholar, who adopts or refuses to adopt a new technology, we shall not focus on this level. In a social science perspective, we are more interested in the environment that heavily influences innovation decisions. In some respects, the decisions are even not taken at the individual, but at an organizational level – for instance by a university, a scholarly association or a single research institute. Furthermore, the organizational and individual levels influence each other, as individuals shape decisions at the former level, too. Complex diffusion networks with opinion leaders, innovative entrepreneurs, external change agents and a mass of adopters of varying innovativeness shape the process.

The core assumption of the analytical framework of actor-centred institutionalism is that social phenomena are to be explained as the outcome of interactions among intentional actors – individual, collective or corporate actors, that is – but that these interactions are structured, and the outcomes shaped, by the characteristics of the institutional settings within which they occur (Scharpf 1997, p. 1).

This approach places its focus on institution-based information, as in many cases it 'will be sufficient to derive satisfactory explanations, and it makes pragmatic sense to reduce levels of abstraction only gradually in the search for theoretical explanations' (Scharpf 1997, p. 42). Following this line of reasoning, the academic culture, the legal environment and economic constraints have to be considered in depth (beyond the activities of individuals) since they shape what the actors perceive as feasible options.

In sum, a number of institutional, functional, technical and actor-related factors play a role in our research puzzle. These factors will not only help us to understand the status quo but will also contribute to future development. Note that limitations and problems perceived during diffusion not only impact on the move from traditional scholarship to cyberscience, but also on the development of the technologies (from first to second generation[3] cyberscience ICT). Along the diffusion path, ICT tools are gradually adapted to the needs of academe; in other words, academic practices (co)construct them. Although set as the main independent variable in this model here (because which technologies are available is mainly developed outside academe), technology can also be viewed as a dependent variable as it is socially shaped (within academe), in particular if we deploy a wide notion of 'technology' that encompasses the related social practices beyond the hard- and software proper. Which technologies become further developed and get used not only depends on the characteristics of the technologies, but also on the nature of the social groups that are using them and for what purposes (cf. MacKenzie & Wajcman 1988; Walsh & Bayma 1996, p. 361). Hence, the academic practices are the mechanism by which the various factors shape the evolution from first- to second-generation tools.

For all three groups of intervening factors, we find some factors that are important for an explanation of the status quo and of trends in academe as a whole, and a more specific subgroup of factors that are relevant for explaining the differences of ICT use between the academic (sub-)disciplines. To outline these factors will be the purpose of the three next sub-sections. While these will be mainly descriptive, we shall enrich the analysis with findings from our empirical research. Furthermore, the subsequent section will discuss how these factors relate to each other, followed by the final element of the model, namely trend extrapolation.

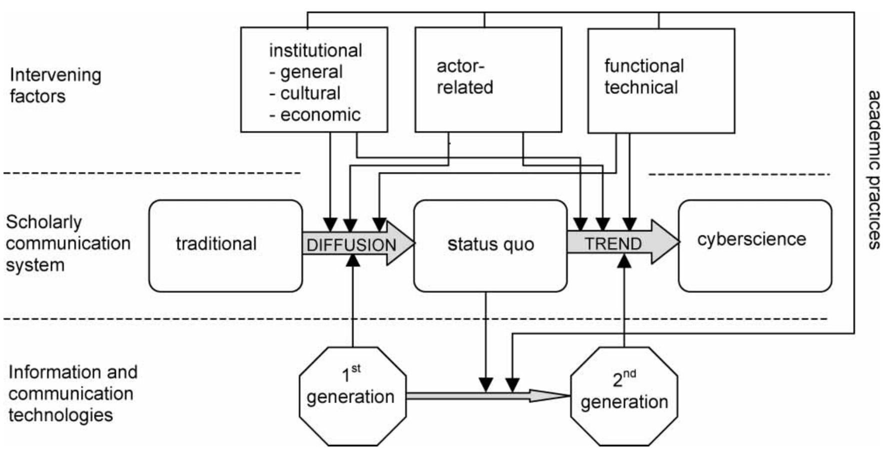

FIGURE 1 Modelling ICT-induced change of the scholarly communication system. *Source*: Nentwich (2003, p. 38).

Institutional factors

Both diffusion research and STS studies have pointed out that institutions, in a broad sense, play an important role when it comes to explaining why technologies diffuse and why they are shaped in a certain way. For my purposes here, it seems useful to distinguish between three types of factors at the institutional level: (1) general coordinates, (2) economic factors and (3) cultural parameters (for more details see Nentwich 2003, pp. 38–45).

(1) A number of *general coordinates* set crucial framework conditions on the level of law, politics and disciplinary environment. The legal environment plays an important role. In particular, the uncertainties of how problems related to copyright issues in the digital environment will be solved contributes to the set of intervening factors. While, already, many publishers accept that a submitted paper has been previously posted to an electronic pre-print archive, many still do not allow this and hence academic authors are hesitant to use these new tools. Our empirical research (expert interviews) shows that legal uncertainties are considered remarkably important with regard to sharing information on the Internet. Furthermore, how politics engages in science and research, i.e. the policy environment, influences, for instance, whether international cooperative networks and projects are favoured. A prime example is the research policy of the European Union, which not only favours cross-national cooperation but also asks for common homepages, shared workspaces and offers software to submit proposals and contract details.

    At the level of (sub-)disciplines, the overall number of active researchers in a speciality and their distribution around the globe could be of importance. One hypothesis is that the smaller and more specialized a community of researchers is, the more likely it will be dispersed, and the more important it could be to have the opportunity to keep in contact and to collaborate via ICT. Our own empirical evidence does not show, however, such a direct correlation, with the exception of the tiny, dispersed and highly 'cyber' field of papyrology. Furthermore, formal communication via publications may be affected by size because the number of potential readers directly affects pricing and hence the likelihood to shift online. This is often the case in the humanities, for instance in history and language studies where some previously paper review journals have been replaced by lively E-journals because the former did not reach enough paying subscribers any more.

(2) ICT hardware and software, including appropriate access to the networks and fees for databases etc. require a considerable budget. Therefore, we should expect *economics* to play a role. In particular, the overall budgetary situation of academic libraries and research units (institutes, universities

and associations) has had an impact, as is documented by the outcry of the librarians in the continuing serials crisis (e.g. Okerson 1997). Furthermore, the cost of publishing influences the attractiveness of this alternative route.

At the disciplinary level, one may hypothesize that the more applied the research in a sub-discipline is, i.e. the more likely commercial application is, the smaller the openness towards a system of free (E-)pre-print publication or, more generally, towards sharing information. This should relate to the ownership of the information: these researchers have good reasons not to share research methods, materials and results, as the work can be lucrative and is often highly competitive (similarly Kling & McKim 2000, p. 5). The prime example in this respect is certainly biotech research. Free E-journals or E-pre-prints are virtually unknown in this field. The human genome (HUGO) project is only partly a counter-example, as it is not applied, but basic research. Furthermore, data are shared through a database, but there are strict rules as to how the data may be used by others. Furthermore, this variable affects the average budgetary situation of a speciality and, hence, the availability of state-of-the-art technology. In general, some of the humanities fields are under-financed, as they do not 'sell' as easily. By contrast, researchers in the more theoretical field of high-energy physics share pre-prints to a large extent.

(3) Obviously, various *cultural parameters* affect the changeover from the traditional ways of doing research to potential new modes. On a general level, the overall prestige of paper in academe influences the path to E-publishing. Not only in our sample of researchers do the majority 'love books' and are reluctant to give them up. There are, however, cultural changes under way, as scholarly papers are increasingly considered technical communications that can be entrusted to the digital world. What many general 'science' studies have shown also plays an important role in our context here: the differences in the professional cultures among disciplines (e.g. Becher 1989). This can be treated at the level of encompassing 'science families' (which is not of high explanatory power, see Nentwich 2003, pp. 164ff.), but also more specifically. For instance, the publishing tradition in a field turned out to be a very important factor. Whether books play a prominent role or not influences the likelihood of 'going online'. While it is not true that book orientation automatically leads to less cyber-publishing, E-journal prestige is lower and there are fewer E-pre-prints and E-journals. This general statement holds for all fields in the sample but historical research (where we find many E-publishing activities despite a traditional book culture).

Disciplines differ also in other respects. Whether a discipline is, in general, rather competitive or rather collaborative influences both publishing and collaboration practices. Furthermore, interconnectedness, the degree to which the researchers in a field are linked by interpersonal networks, is positively related to innovativeness (Rogers 1995, p. 381). Indeed, my empirical sample confirms this hypothesis: the more collaborative a field is, the more E-conferences and databases we find. The mutual visibility of ongoing work in the field (transparency) is also related to interconnectedness and may be positively related to a favourable attitude towards the online sharing of reports and data (Kling & McKim 2000, p. 5).

Technical and functional factors

A major outcome of diffusion research is that innovations will be adopted more rapidly than other innovations in case individuals perceive them as having greater relative advantage over the earlier technology. In addition, higher 'compatibility', that is consistency with both the existing values and the needs of potential adopters, positively influences adoption behaviour (Rogers 1995, p. 16). In other words, the innovation has to offer a positive cost–benefit balance. We may distinguish between (1) purely technical and (2) functional aspects of this account of compatibility and advantage. It seems equally possible to discuss the technical properties, not as intervening factors but rather as part of the independent variable ICT, because they determine the supply side. Here, I have chosen to analyse them separately with a view to stressing their importance in the diffusion process. Note that these factors, like all others discussed here, are not sufficient causes for diffusion. That is, whether an application is functional and (technically) well functioning alone is only one among many factors for adoption.

(1) *Technical properties* of ICT play an important role to see whether or not researchers will use ICT and whether the new media will be apt to fulfil their communicative needs. On a first level, I observe that the new technologies have specific properties distinguishing them from the traditional communication media (e.g. the phone), such as asynchronity or speed or multimedia. In principle, these properties enable the researcher to establish new forms of communicative links. Whether or not they will actually do so depends, above all, on the attractiveness of the innovative features – the 'perceived usefulness' (Kirkup & Jones 2000). It has been observed, for instance, that the Internet only appealed to the masses (also among scientists) when the rather clumsy text- and list-based older interfaces like Gopher were replaced with the World Wide Web technology that allows for easy graphical browsing. Other examples are digital libraries (Harter 1996, p. 1) and newsgroups (Lewenstein 1995, p. 125). This is technically not possible without the electronic media. In

more general terms, we may say that the user interface is very important. This is not to say that researchers would not accept a less convenient technology for a while if the other advantages were still considered very important. In the long run, however, we may hypothesize that only 'ripe' technologies are able to convince the critical number of participants (this does not exclude that academics may play an important role as early adopters – and they actually do so frequently). User-friendliness of the software is one important element as regards the potential for widespread use. One example in this respect is the potential usefulness of 'discussion' lists for genuine academic debates. While these list servers seem to be universally accepted for information exchange, interviewees in most fields complained about the difficulty to follow threaded discussions over a longer period – something that has to do with user interface design.

Obviously, one of the more important issues hindering or favouring the widespread use of some of the new ICT is screen technology. ICT is based on digital technologies requiring its users to read on and look at screens all the time. For sure, researchers often reduce the on-screen time as much as possible, for instance through printing the content displayed on-screen. In many cases this strategy seems well suited, e.g. for conventional papers downloaded from the World Wide Web. However, many of the possible advantages cannot be enjoyed off-screen. Think of a video clip recording an experiment, a dynamic database or a videoconference. Here, screen technology is paramount and already there seem to be a number of promising new technologies making digital screens as good a display technology as paper (so called 'E-paper'). Closely related is independence from constant power supply for long periods, as well as physical robustness. With working habits of academics in mind, the experts interviewed for this study almost univocally confirm that large-scale reading on-screen will only take place with next-generation portable displays.

Anyone who has participated in an online Internet videoconference will probably acknowledge the promising potential of this new technology. However, restrictions of the bandwidth of the network make it still a mixed experience. Sufficient bandwidth is also important for convenient (real-time) database access and online collaboration when synchronicity is key, in particular given the constantly rising number of network users inside and outside academe. The current endeavours to install academic high-speed broadband networks like the GÉANT and the Grid technology will lead the way into the future.

A further important technical factor is the reliability of the hardware and software. As long as trust in the technology is severely hampered due to frequent personal experiences with computer crashes, network failures and data loss, it is rather likely that the relatively secure conventional communication channels, in particular publishing on paper as opposed to E-publishing, will remain the first choice.

Also archiving of scholarly communication – although not solely a technical but also an organizational problem – needs to be addressed in a convincing and sufficient manner before scholars will be inclined to entrust their research communication to the digital world. A large majority of the interviewees mentioned this factor.

From a *functional perspective*, first, faster media are more welcome in those disciplines with higher time constraints. In other fields, a relatively slow pace of discovery limits benefits. Indeed, in our 13 disciplines comparison, the 'faster' ones have more E-journals and more E-pre-prints. For instance, the 'half-time' of knowledge is quite different and hence may influence whether fast and up-to-date information (as promised by E-publishing) is important. A prime example in this respect is economics with huge E-print databases. Disciplines also vary as to their visual or non-visual orientation. In those fields where multimedia communication offers substantial improvements, the likelihood of their implementation is indeed higher (for instance pre-history or molecular oncology). The same applies, in principle, to intense dependency on data where the computer has always played a substantial role and the networked computer offers promising opportunities. Therefore, we find more disciplinary databases and virtual institutes in these fields (e.g. meteorology).

Actor-related factors

Actors are crucial in the diffusion of technologies. On the one hand, individual and collective actors are the basic units adopting innovations. We can distinguish between (1) aspects important for individual behaviour and (2) factors playing a role at the organizational level. On the other hand, the history of innovation has highlighted the importance of agency for the process of diffusion (3).

(1) There can be no doubt that variables at the *individual* level account for different communicative behaviour. First, a researcher's reputation, status and career stage, as well as age, influence how likely particular forms of communication are and with whom one communicates. Another major factor influencing the individual's communicative preferences is the familiarity with and – related to this – one's general attitude towards technology in general and ICT in particular. There are rather 'passive' people who use only what is available and what they are forced to, and there are 'activist' researchers who actively explore the new opportunities. Furthermore, experiences with past cooperation

will impact on whether an individual is likely to engage in new collaborative endeavours, in case they are not absolutely essential for the type of work she/he is carrying out. Related to the first point (status) is what we may call 'individual peripherality'. Access to informal networks and to physical meeting places is not equally distributed and available to everyone. Both impact on whether technologies enabling exchange and meeting over distance are attractive.

Certainly, these individual factors account for variation in usage and, on an aggregated level, for a particular communicative culture. However, it seems likely that if the overall trend is different from what individuals (or groups) prefer, the individuals will adapt in the long run. Take the example of submitting manuscripts to a journal: while a traditional journal may still accept submissions on paper, E-journals mostly do not. If researchers want to publish in such a journal, they have to send a digital paper. Hence, there is both an imitation and a pull effect as the example of others influences individual behaviour. After surpassing a certain minimum threshold of people using a specific application, of quoting a particular E-journal or contributing to a common knowledge base, the incentive for latecomers to join increases. Critical mass is often necessary (Grudin 1994).

Interestingly, our empirical findings show that the more senior and highest-ranking researchers have a third option: their Internet communication is mediated by their offices (secretariats or assistants). They participate without being directly involved. Some of them tried email, perhaps even on a broad scale, but eventually 'retired' and sourced out.

(2) Other factors come into play at the *organizational* level (e.g. research institutes). I have already mentioned funding as an important factor. In many cases, this will correlate with whether the research institute is to be considered 'core' or 'periphery' within the discipline, i.e. with its reputation. However, there is more to reputation than financial resources and hence infrastructure. It also influences directly the communication needs: the more at the centre of a speciality an institute is, the less need there is to engage actively in establishing communication since the others will seek contact. This may not only play at the level of the individual research institute, but the academic peripherality or centrality of the country will influence how important it is to establish communicative links. Furthermore, the number of researchers at a given institution influences the need for external communication and hence ICT. The smaller the institute, the more a researcher will seek feedback and information from outside. However, if there are a critical number of researchers at one spot, a new demand for technology-supported internal communication may arise (note that the World Wide Web was developed at CERN exactly for this purpose). This

hypothesis is matched with a generalizable result of diffusion research, namely that, for the most part, larger organizations are more innovative in the sense that diffusion may proceed quicker (Rogers 1995, p. 379).

Next, something we might call 'internal culture' may influence how an institution communicates. By culture, I mean for instance the habit of frequent face-to-face meetings in the form of a 'jour fixe' or regular internal seminars or a meeting place like a cafeteria, as opposed to a more solitary working style with closed office doors. In more general terms, the degree to which the researchers are linked by interpersonal networks ('network interconnectedness', Rogers 1995, p. 381) is favourable to the degree of innovativeness of an organization. Institutional persistence is a final factor to be listed here. If the move to a new technology involves a large step, it is likely that we shall see individual institutions to retard the development, for instance by not providing the respective E-journals infrastructure.

(3) *Agency*, the role of innovators (active information seekers who are inclined to adopt earlier), opinion leaders (who are able to influence other individuals) or even innovation champions (charismatic individuals who throw their weight behind the innovation, thus overcoming indifference or resistance, cf. Rogers 1995, p. 398) play an important role in any diffusion process. In our context, those individuals who dare to use innovative E-journals or new communication channels first (trailblazers), and the presence and activities of entrepreneur-minded researchers in a field, are crucial. Many of the outstanding developments, like the World Wide Web itself or the first E-pre-print archives, would not have been such or so early a success if there had not been a few driving individuals. Gresham (1994, p. 48) calls this 'electronic altruism'. In turn, the reputation of the authoring or editing institution promoting an E-journal may be related to the success of such an initiative.

The relationship between the intervening factors

The various factors outlined above play a role at different levels and contribute differently to an overall explanation of ICT use in academe. Furthermore, we face the usual social science problem, namely the sheer number of intervening variables, and the impossibility of doing experiments in which we would be able to hold constant all but one variable. It is the purpose of this subsection to complete the 'change model' by elucidating the relationship between the various factors.

Some factors relate to academe as a whole; others play at the disciplinary level; and a third group helps us to understand individual innovation decisions (either of individual researchers or of organizations). The general technical factors and some of the institutional factors belong to the first group. We find factors playing at the disciplinary level in the institutional, functional and actor-related groups of factors, whereas most actor-related factors and the functional aspects related to the task level are in the third category. Let me look at these groups in turn.

In this model, as with sociological research in general, we are *not interested in the explanation of individual cases*. Innovation decisions taken by individual researchers and organizations (research units, associations etc.) are only relevant for this model at an aggregated level. Differences at the individual level either cross each other out or are visible at the next level, that is, at the level of disciplines or countries. If a large majority of individual researchers in a field show the same preference, this would suggest that this is not only an individual characteristic, but also one at the next analytical level. For instance, the existence of cyber-entrepreneurs and the reputation of the editing institution of a new E-journal (agency) become relevant at the disciplinary level. Another example is peripherality and 'digital divide'. There is a strong case that whether a research institute (or country) belongs to the core of its discipline or not, is an important variable for the usefulness and hence the level of ICT use.

By contrast, those *factors relevant for academe as a whole* are important here, as they will inform any impact analysis at various levels. In particular, the various factors playing at thedisciplinary level are central to a comparison of the status quo and development of ICT use in academe (Nentwich 2003, ch. 3). We shall come back to them in the next section.

The *technical variables represent a special case* in this model. On the one hand, they influence innovation decisions and hence connect the individual with the general level. On the other hand, they are highly dynamic. One may argue that they will become less and less important as time goes by. User interfaces are being improved based on the feedback of first-user experiences. The continuous development of new applications (within and outside academe) presents a big incentive for early adopters to try them out, to give feedback to the developers and thus accelerate the development. Innovative applications seem to be mainly developed by a small group of people, reinforcing each other in a feedback loop. Network bandwidth is still too small for the more sophisticated multimedia real-time application, but given the worldwide efforts to realize high-speed networks, this seems only a matter of time, too. Therefore, the technical factors contribute to our understanding of the dynamics of the move from first- to second-generation ICT and from traditional to cyberscience. They are largely the same for everyone in every field everywhere. For instance, archiving is not discipline-specific and will probably be resolved on a meta-level within academe. The reliability of computers and screens is even independent from academe.

To sum up, on the one hand, it is necessary and fruitful on a conceptual level to distinguish between all factors possibly influencing how ICT impacts on all aspects and instances of scholarly communication. On the other hand, the above discussion reveals that, for the purpose of generating generalizable insights about the overall impact on research, it is not useful to consider in more depth each and every one of these intervening factors. Not all of them can or do contribute, for logical and empirical reasons, to an explanation on an overall level. Some of them may play a role only in explaining individual cases. In aggregated form, others may be part of the main group of factors, namely those that distinguish the various sub-disciplines. While being important in the long run, a last group of factors (e.g. screen technology) is considered to be of diminishing importance if one looks a few years into the future when these technological problems will most probably be solved.

In the next section, I shall come back to this discussion of the relationship between the various factors and how they play at the disciplinary level.

Qualitative trend extrapolation

The final element in the analytical 'change model' is the extrapolation of the developments with a view to drawing a differentiated and realistic picture of how ICT is changing the SCS in the near future. Note that this involves two interrelated foresight enterprises, namely of the technology (ICT) and, to some degree, the social system (academe), which are done simultaneously (Porter *et al.* 1980, p. 146).

There is not enough relevant information available for quantitative mathematical-statistical calculations, i.e. for trend extrapolation in the narrow sense (Porter *et al.* 1908, pp. 115 ff.). The general statistical material published by organizations such as the OECD does not focus on ICT use in academe. Theoretically, it would be possible to gather data on computer use in academe in many dimensions (for instance, figures on E-journal use etc.). However, apart from the enormous practical problems of this endeavour, it would be nearly impossible to get reliable data on the past, with a view to calculating any trends. As there was and is no system of automatic recording of ICT use, one would need to rely on *ex post* estimations of interviewed researchers. While such information gathering may be useful in a qualitative sense with a view to overall trends, it would be highly dubious to base mathematical-statistical computations on such vague information. What is more, we cannot assume that any past trends would continue unchanged into the future. It is all but sure that curves would indeed be S-shaped, as discontinuance is an immanent possibility. Furthermore, we cannot say for sure what proportion of the whole population of researchers would ever adopt the new technologies (or which sub-set thereof) as we cannot know in advance whether the new technologies will replace or only complement older technologies.

In short, such a trend extrapolation has to be a *qualitative assessment*, for both theoretical and practical reasons.

This trend analysis rests – similar to the first part of the change model, which aimed at explaining the status quo – on the assumption that the intervening factors will play their role here, too. There is no reason to hypothesize that the factors will not influence the future development as they have done in the past. Without a doubt, a number of factors are evolving along the path to cyberscience. In particular, the technical factors are changing not only in their empirical state but also in importance as time goes by. In addition, the legal environment is changing constantly, as is, to a certain degree, the science policy environment. Furthermore, even general coordinates (such as the size of a field or its distribution around the globe) are not fixed. We shall have to take due account of this inherent dynamic. Most factors, however, are not likely to change in the period observed here, as we are intending to look only a few years into the future.

Important elements of such a qualitative approach have to be the results of empirical inquiries, in particular of the trend assessments of experts. Furthermore, a comparative approach may be helpful in special cases. As already mentioned, some of the disciplinary variables are dynamic in the sense that they are not fixed but evolve over time. This puts us in a position to draw some cross-disciplinary conclusions related to the timing of developments. If we find the same set of features (values of variables) in two sub-disciplines, but different outcomes (i.e. levels of cyberness), then we may infer that, most probably, the discipline with the lower level of cyberness was just late to experience ICT and may 'catch up' soon. Diffusion of technologies is never simultaneous but its spreading over time is contingent upon historic and other circumstances (as discussed in diffusion research). Only if this condition is met, i.e. if the two cases show the same variable configuration, would this inference be allowed – with much prudence, though, since there is always the possibility that we have overlooked any case-specific conditions.

Past research in the diffusion of technologies has shown that 'interactive technologies' are a special case. First, the benefits of an interactive innovation flow both backward in time to all previous adopters and forward in time to all future adopters (Rogers 1995, p. 315). Second, above a critical number of adopters, the 'further rate of diffusion becomes self-sustaining' (Rogers, 1995, p. 319). Communication technologies, such as the Internet, are model interactive innovations. In addition, the diffusion of communication technologies is reflexive (and hence self-reinforcing) as the innovation is using itself as a communication channel. Email and the World Wide Web, now almost universal, are the most important channels for diffusing knowledge about new ways of doing on the World Wide Web. Furthermore, additional conditions for successful diffusion processes (Rogers, 1995, pp. 379 ff.) are met in academe: network interconnectedness is high in academe; there are relatively many uncommitted resources available ('organizational slack'); the system is relatively open as researchers are linked not only internally, but also to individuals external to academe; in academe, somewhat informal structures prevail, it is rather not bureaucratic, and highly decentralized. Finally, it is known that innovations may be changed or modified by users in the process of adoption and implementation ('reinvention'). This enhances the so-called 'trialability' and may also contribute to more compatibility of the innovation. Reinvention obviously occurs frequently along the path to cyberscience, for instance as regards the management of E-journals (tools and procedures). In sum, starting from these general observations based on diffusion research, we may expect that the diffusion of interactive Internet-based tools will continue and may reach a self-sustaining level.

Disciplinary differences: the model and the status quo

The model as outlined in the previous section can be used as the basis of empirical research that compares the status quo with trends in a number of research fields (see Nentwich 2003, pp. 107ff.). I have already alluded to some of the findings and will now present the main results in a condensed form. Table 1 distinguishes various dimensions of ICT use in academe and summarizes those factors that contribute most to an explanation of the differences between the disciplinary fields.

As we are focusing on an analysis of the influence of communication technologies, it comes as no surprise that a sub-discipline's collaborative culture is important. Equally, a pre-existing pre-print culture strongly favours the establishment of E-pre-print servers. A general time pressure and faster pace of generating new results let researchers be more open to new forms of cyber-publishing. In general, more book-oriented fields are less inclined to go for E-pre-print servers and E-journals. A field's cumulative tradition favours both digital libraries and disciplinary databases. Whether a subject area is data-dependent and model-driven affects the likelihood of many disciplinary databases and virtual institutes. Closeness of the field to economic applications has a negative influence on the existence of both E-pre-print servers and disciplinary databases. Sub-disciplines applying more uniform styles and methods are more likely to favour E-pre-print servers. As regards multimedia, more visually oriented fields are at the forefront but, so far, technical rendering problems hamper its success. On a general level, it can be said that better funding and a more international focus of the research field favour ICT use. The existence of cyber-entrepreneurs may further account for the general level of ICT use in a speciality.

TABLE 1 Influencing factors for ICT use

dimensions of 'cyberness'		*influencing factors*
E-pre-print servers	+	Uniformity of style or methods
	+	Pre-print culture
	(+)	Time pressure
	(+)	Pace of discovery
	–	Book orientation
	(–)	Closeness to economic application
E-journals	+	Time pressure
	+	Pace of discovery
	(+)	Reputation of editors
	(–)	Book-orientation
Digital libraries	+	Cumulative tradition
Multimedia	(+)	Visual orientation
	–	Rendering problem
Disciplinary databases	(+)	Data-dependent, model-driven
	(+)	Cumulative tradition
	(+)	Collaborative culture
	(–)	Closeness to economic application
E-conferencing	(+)	Collaborative culture
Virtual institutes	(+)	Data-dependent, model-driven
ICT use in general	+	Cyber-entrepreneurs
	(+)	International focus
	(+)	Funding

Notes: + ··· Positive influence; – ··· Negative influence; () ··· partly.
Source: Nentwich (2003, p. 180).

As expected, I cannot identify a set of variables that could explain all cases. It is rather the varying combination of a number of them that contributes to an overall explanation. Hence, the resulting picture is one of multiple causation. No single factor is able to explain all cases. Furthermore, the various factors interact and are often interdependent. In sum, there are neither necessary nor sufficient causes for 'cyberness' of a field. It seems plausible to assume that a configurable technology such as the World Wide Web can be adopted and used by different fields in different ways (Kling & McKim 2000, p. 3). Not only that the new media are actually used, but also how they are used and shaped is specific to the needs of the communities. We are therefore likely to see continuous differences among the various fields instead of convergence. Cyberscience will never be uniform across fields and it will stay a moving target for research.

Conclusions

The model presented in this article is neither a causal nor a probabilistic model, but rather a heuristic tool that rests on qualitative assessments. It helps us understand the complex process of change of the scholarly communication system that is triggered (though not determined) by technology change. The model provided us with a series of hypotheses about potential intervening factors that may explain the differences in use of ICT among the research fields. The empirical evidence shows that we cannot explain the differentiation by a parsimonious set of variables. By contrast, various configurations of institutional, functional and actor-related factors contribute to our understanding of reality. Our synthesis shows that, above all, the different disciplinary cultures – publication traditions, collaborative practices and a cumulative way of doing research – turn out to rather be more important than the usual suspects (such as internationality of a field, size of the community and membership in a 'disciplinary family').

This 'change model' could be used to inform further comparative research on ICT use in science and research. While restricted here mainly to the communicative aspects of cyberscience, it is encompassing enough to frame research into further dimensions, such as simulation, grid computing and artificial intelligence. Together with the so-called 'impact model' (Nentwich 2003, pp. 50ff.) that describes the consequences of these changes in the scholarly communication system for academe as a whole, and the substance of research in particular, we have a powerful conceptual tool to assess the future of science and research in the age of the Internet.

Notes

1 The term 'ICT' often comprises not only the analogue or digital transmission of data to connect people to people and to machines, but also the machines (in a wider sense) that process the information themselves (computers, instruments, software, databases). Here I shall focus on the subset of communication technologies in a narrower sense, in particular on the Internet as the main novel technology. Note, however, that other subsets of ICT – the 'research tools' – also affect the outcome of research activities, as they are the means to treat the research questions (expert systems, artificial intelligence, simulation, distributed and grid computing etc.). They are, however, increasingly inseparable from communication technologies in a stricter sense.

2 The 50 interviewees worked in Austria, Germany and the Netherlands. The great majority of them were established scholars in their fields and well embedded in the international community. I used a semi-structured,

partly open questionnaire. The interviews lasted between one and three hours each and took place, in most cases, face to face in the office of the scholar. The interviews have not been tape-recorded; the interviewer's notes formed the basis for entries in a detailed database mapping the state-of-the art and prospects of ICT use in the various fields.

3 First-generation ICT are those tools that are not only available today, but are also used wide-spread in most disciplines (e-mail etc.). By second-generation tools, I understand those that are presently being developed and experimented with only on a limited basis and which may gain influence soon (video-conferencing etc.).

References

Becher, T. (1989) *Academic Tribes and Territories*, Open University Press, Milton Keynes.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P. & Trow, M. (1994) *The New Production of Knowledge – The Dynamics of Science and Research in Contemporary Societies*, Sage Publications, London.

Gresham, J. L. (1994) 'From invisible college to cyberspace college: computer conferencing and the transformation of informal scholarly communication networks', *Interpersonal Computing and Technology*, vol. 2, no. 4, pp. 37–52. [Online] Available at: http://www.helsinki.fi/science/optek/1994/n4/gresham.txt (2 November 2005).

Grudin, J. (1994) 'Groupware and social dynamics: eight challenges for developers', *ACM'94*. [Online] Available at: http://www.ics.uci.edu/~grudin/Papers/CACM94/cacm94.html (2 November 2005).

Harter, S. P. (1996) 'What is a digital library? definitions, content, and issues', KOLISS DL '96: International Conference on Digital Libraries and Information Services for the 21st Century (1996-09-10/13): Seoul, Korea. [Online] Available at: http://www.php.indiana.edu/~harter/korea-paper.htm (2 November 2005).

Kirkup, G. & Jones, A. (2000) 'Information and communication technologies in distance and lifelong learning', in *The Information Society in Europe – Work and Life in an Age of Globalization*, eds K. Ducatel, J. Webster & W. Herrmann, Rowman & Littlefield, Lanham, MD.

Kling, R. & McKim, G. (2000) 'Not just a matter of time: field differences in the shaping of electronic media in supporting scientific communication', *Journal of the American Society for Information Science and Technology*, vol. 51, no. 14, pp. 1306–1320 (cited from manuscript). [Online] Available at: http://www.xxx.lanl.gov/ftp/cs/papers/9909/9909008.pdf (2 November 2005).

Lewenstein, B. V. (1995) 'Do public electronic bulletin boards help create scientific knowledge? The cold fusion case', *Science, Technology & Human Values*, vol. 20, no. 2, pp. 123–149.

MacKenzie, D. & Wajcman, J. (1988) *The Social Shaping of Technology – How the Refrigerator got its Hum*, Open Unviversity Press, Milton Keynes.

Nentwich, M. (1999) *Cyberscience: Die Zukunft der Wissenschaft im Zeitalter der Informations- und Kommunikationstechnologien*. Working papers, Max-Planck-Institute for the Study of Societies. Cologne. [Online] Available at: http://www.mpi-fg-koeln.mpg.de/pu/workpap/wp99-6/wp99-6.html (2 November 2005).

Nentwich, M. (2003) *Cyberscience: Research in the Age of the Internet*, Austrian Academy of Sciences Press, Vienna. [Online] Available at: http://www.hw.oeaw.ac.at/3188-7 (2 November 2005).

Okerson, A. S. (1997) 'Midnight in the Garden of Good and Evil? Libraries, academic publishing, copyright, and other miasmas'.[Online] Available at: http://www.library.yale.edu/~okerson/okerson-sf.html (2 November 2005).

Porter, A. L., Rossini, F. A., Carpenter, S. R., Roper, A. T., Larson, R. W. & Tiller, J. S. (1980) *A Guidebook for Technology Assessment and Impact Analysis*, System Science and Engineering: 4, North-Holland, New York–Amsterdam–Oxford.

Rogers, E. M. (1995) *Diffusion of Innovations*, Free Press, New York–/London.

Scharpf, F. W. (1997) *Games Real Actors Play. Actor-Centered Institutionalism in Policy Research, Theoretical Lenses on Public Policy*, Westview Press, Boulder, CO–Oxford.

Walsh, J. P. & Bayma, T. (1996) 'The virtual college: computer-mediated communication and scientific work', *The Information Society*, vol. 12, no. 4, pp. 343–363.

Walsh, J. P. & Roselle, A. (1999) 'Computer networks and the virtual college', *Science Technology Industry Review (OECD)*, vol. 24, pp. 49–78.

Wouters, P. F. (1996) Cyberscience, *Kenntnis en Methode*, vol. 20, no. 2, pp. 155–186.

Michael Nentwich, PhD, has been senior scientist at the Institute of Technology Assessment of the Austrian Academy of Sciences in Vienna since 1996. He previously lectured and researched at the Research Institute for European Affairs (Vienna University of Economics), was a Human Capital Mobility Fellow at the Universities of Warwick and Essex (1994–95), and guest researcher at the Max Planck Institute for the Study of Societies Cologne (1998–99). He studied law, political science and economics in Vienna and Bruges. In 2004, he completed his 'habilitation' procedure at the University of Vienna in science and technology studies. His recent research focuses on technology assessment in the field of information and communication technologies. He has published *inter alia* eight books and over 30 articles. He also serves as the editor of an E-journal and as webmaster. *Address*: Institute of Technology Assessment, Austrian Academy of Sciences, Strohgasse 45/5, A – 1030, Vienna, Austria. [email: mnent@oeaw.ac.at]